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DISTRIBUTION AND ABUNDANCE OF INDO-PACIFIC HUMP-BACKED DOLPHINS (*SOUSA CHINENSIS* OSBECK, 1765) IN HONG KONG WATERS

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'For this is the perfect "beginner's dolphin." Large, slow, gently "tame" and unmistakable — white and pink as a baby's bottom — it literally shines out of the South China Sea even as much as half a mile away.'

Harrisson (1959)

Abstract

Line transect surveys to examine the distribution and abundance of Indo-Pacific hump-backed dolphins (*Sousa chinensis* Osbeck, 1765) in Hong Kong waters were conducted from November 1995 to May 1997, as part of an ongoing study to provide information needed for informed management and conservation. Two observers searched for dolphins while the survey vessel followed pre-determined, random (with respect to dolphin distribution) transect lines. When dolphins were seen, sighting data were collected and photographs were taken to identify individuals. A total of 13,078 km of survey effort was used in calculating sighting rates and abundance. Dolphin sightings occurred in all of the waters surrounding Lantau Island, but were most common in the North Lantau area. Seasonal estimates of abundance in North Lantau were made, using line transect methods. Estimates ranged from 88 dolphins (CV = 19%) in spring to 155 dolphins (CV = 24%) in autumn, with a year-round average of 109 (CV = 12%). One-hundred, one individual dolphins were identified from photographs, and new ones are still being added to the catalog. Preliminary Petersen and Chao mark-recapture estimates of abundance from photo-identification data suggest that between 208 (CV = 17%) and 246 (CV = 17%) different individuals use the Hong Kong area. Survey work continues, to refine estimates, investigate trends in abundance, and examine the effects of various factors on the accuracy of the abundance estimates.

Introduction

Until the start of the 1990s, very few people knew that Indo-Pacific hump-backed dolphins (*Sousa chinensis*) were found regularly in Hong Kong waters; although as early as 1637 and 1751 they were noted as occurring in the Pearl River estuary (Osbeck 1771; Carnac-Temple 1919). There was almost no indication of the presence of these animals in the scientific literature before the present decade, and even Romer's (1958) initial report of cetaceans in Hong Kong made no mention of this species. However, the deteriorating condition of Hong Kong's marine environment, and especially concern raised by construction of Hong Kong's new international airport on reclaimed land at Chek Lap Kok, dramatically increased awareness of dolphins in Hong Kong (Parsons *et al.* 1995). Dolphins quickly became symbols of Hong Kong's lack of regard for the environment in its drive to increase its status in the economies of Southeast Asian countries.

[1] Sadly Dr Leatherwood passed away on 25 January 1997.

Concern about the conservation status of hump-backed dolphins recently led the Agriculture and Fisheries Department of the Hong Kong government to provide funding for studies of the population biology of these animals in Hong Kong (for further details about the political background of this issue, see Leatherwood and Jefferson 1997).

The research project reported here began in the autumn of 1995 and will continue through at least the spring of 1998. The goal is to investigate the population biology and ecology of hump-backed dolphins in Hong Kong and the adjacent Pearl River delta, with special emphasis on aspects directly related to their conservation. Line transect surveys (Buckland *et al.* 1993) and photo-identification of individuals (Würsig and Jefferson 1990), are the primary methods used in this research. Line transect has been used successfully to estimate density and abundance of many species of small cetaceans, including coastal species such as harbor porpoises (*Phocoena phocoena* Linnaeus, 1758) (Barlow 1988; Heide-Jørgensen *et al.* 1992, 1993; Palka 1995). Mark-recapture analysis of photo-identification data has been used to estimate the abundance of several species of small cetaceans, primarily bottlenose dolphins (*Tursiops truncatus* Montagu, 1821) (Blaylock 1988; Hansen 1990; Wells and Scott 1990; Williams *et al.* 1993; Blaylock and Hoggard 1994). Durham (1994) recently used the latter technique to estimate abundance of Indo-Pacific hump-backed dolphins in South African waters.

This paper reports on the results of the first 1.5 years of this ongoing study, discusses the applicability of line transect survey and photo-identification techniques to this population, and discusses some of the future research directions.

Materials and methods

Study area

Hong Kong, for the past 150 years a British Dependent Territory, is situated along the coast of southern China, adjacent to Guangdong Province of the People's Republic of China (PRC). In July 1997, governance of Hong Kong was handed back to China, and Hong Kong became a Special Administrative Region within the PRC. The Basic Law guarantees it a high degree of autonomy for at least 50 years after the handover.

Well over half (1,800 km^2 of the total 2,870 km^2, or 63%) of the territory's total area consists of coastal waters (Choi 1996). Although situated slightly south of the Tropic of Cancer, Hong Kong does not have a strictly tropical climate. However, it does experience high temperatures and heavy rainfall in the summer season, with relatively lower temperatures and much less rain in the winter season (Broom and Ng 1996).

The marine environment of Hong Kong is characteristic of that of the northern South China Sea, but the marine waters of the small territory consist wholly of shallow areas, with depths of less than 40 m; in fact most western waters are less than 20 m deep (Whiteside and Rodger 1996). The major hydrological feature is the fresh water input from the Pearl River, which flows into Hong Kong's western waters (Broom and Ng 1996). The western waters are thus estuarine and are considered to represent the primary habitat of Indo-Pacific hump-backed dolphins in the region. For the purposes of this study, Hong Kong has been divided into eight geographic survey subareas, or strata (Fig. 1). In addition, a small amount of survey effort has been conducted in Pearl River waters just to the west of Lantau Island. Victoria Harbour and Tolo Harbour are considered too degraded to be suitable as cetacean habitat, and thus are not included.

Field methods

A short pilot study, consisting of four informal boat trips, was conducted in the North Lantau area in September and October of 1995. Systematic vessel-based sighting surveys have been conducted since November 1995, with variable frequency, but generally at least six days per month. Acceptable sighting conditions were defined as days with sea state conditions of Beaufort 0–5 and visibility of approximately 1,200 m or greater. Primary transect lines were pre-determined to provide representative survey coverage and were designed without reference to dolphin distribution. They ran north/south or east/west and were

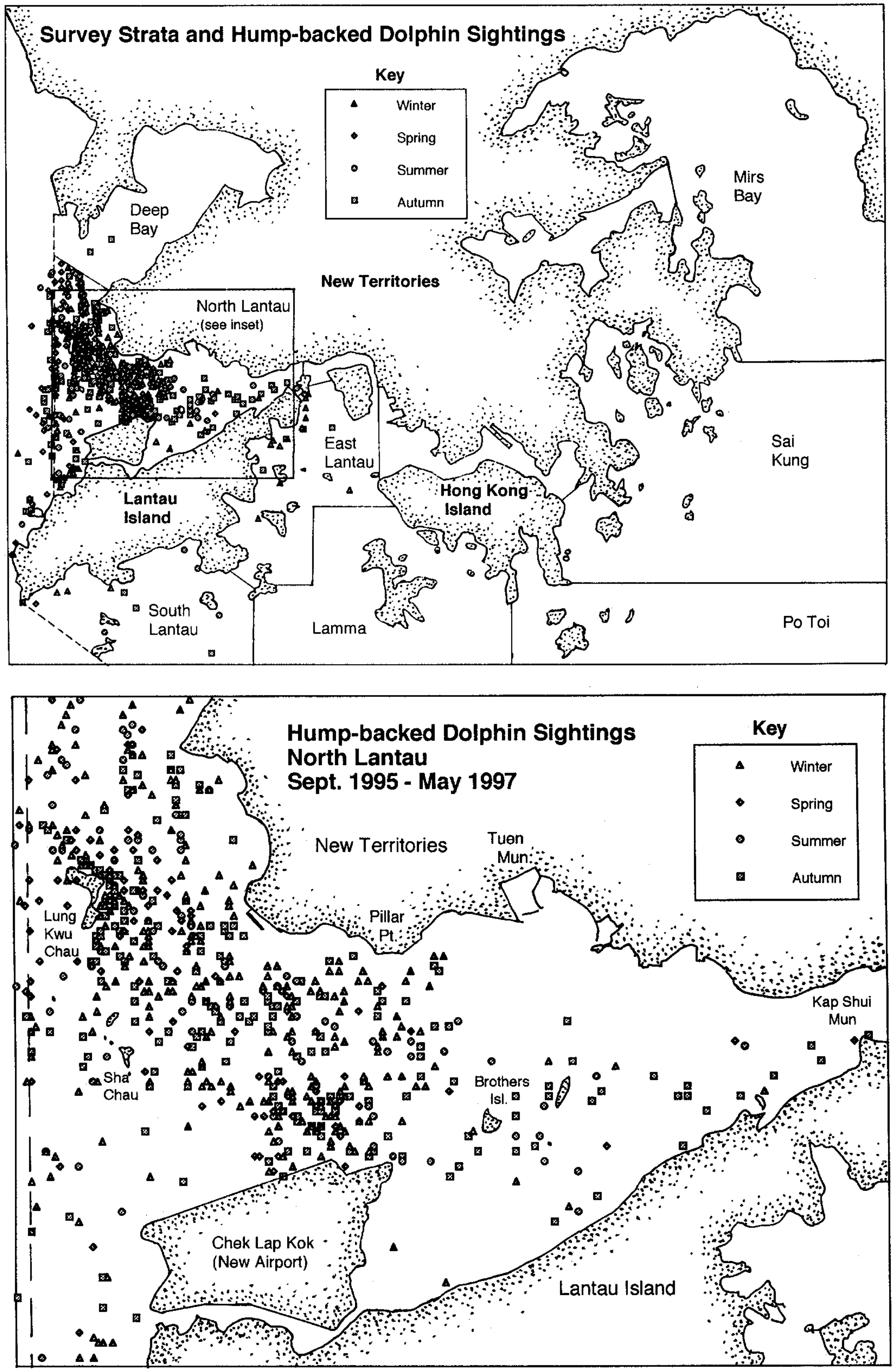

Fig. 1. Map of the study area, showing the eight geographic survey subareas, and distribution of Indo-Pacific hump-backed dolphins in Hong Kong waters, based on systematic sightings from survey vessels. The dashed line represents the PRC boundary during the present study (it has recently been revised).

parallel, spaced 1–3 km apart (Fig. 2). Survey vessels of 10–15 m length, with flying bridge or upper deck areas affording unobstructed forward visibility, were used. The majority of the data were collected from three vessels, the *Sea Horse, Lady Muriel,* and *Harbour Front No. 13*. Observer eye height was 4–5 m above the water's surface. All observers were trained in cetacean survey techniques and proper data collection protocol; the senior author periodically accompanied all survey teams to audit data collection and to calibrate distance estimates (see below).

Two observers searched for dolphins from the flying bridge area, one scanned continuously with 7 X 50 *Fujinon* or *Nikon* marine binoculars (Primary Observer) while the other used naked eye and occasional binocular scans (Data Recorder). A hand-held GPS unit provided continuous data on vessel position, speed, and course. Such data, along with information on sighting conditions were kept by the Data Recorder as the vessel transited the transect lines. When dolphins were sighted, the position and data on sighting angle, distance to the group, group size, and behavior were recorded. Sighting angle was obtained from successive compass bearings on the dolphin group and the vessel's track, and distance was estimated by eye.

Since July 1996, we also have used a pair of 7 X 42 *Leica Geovid* binoculars, with a built-in

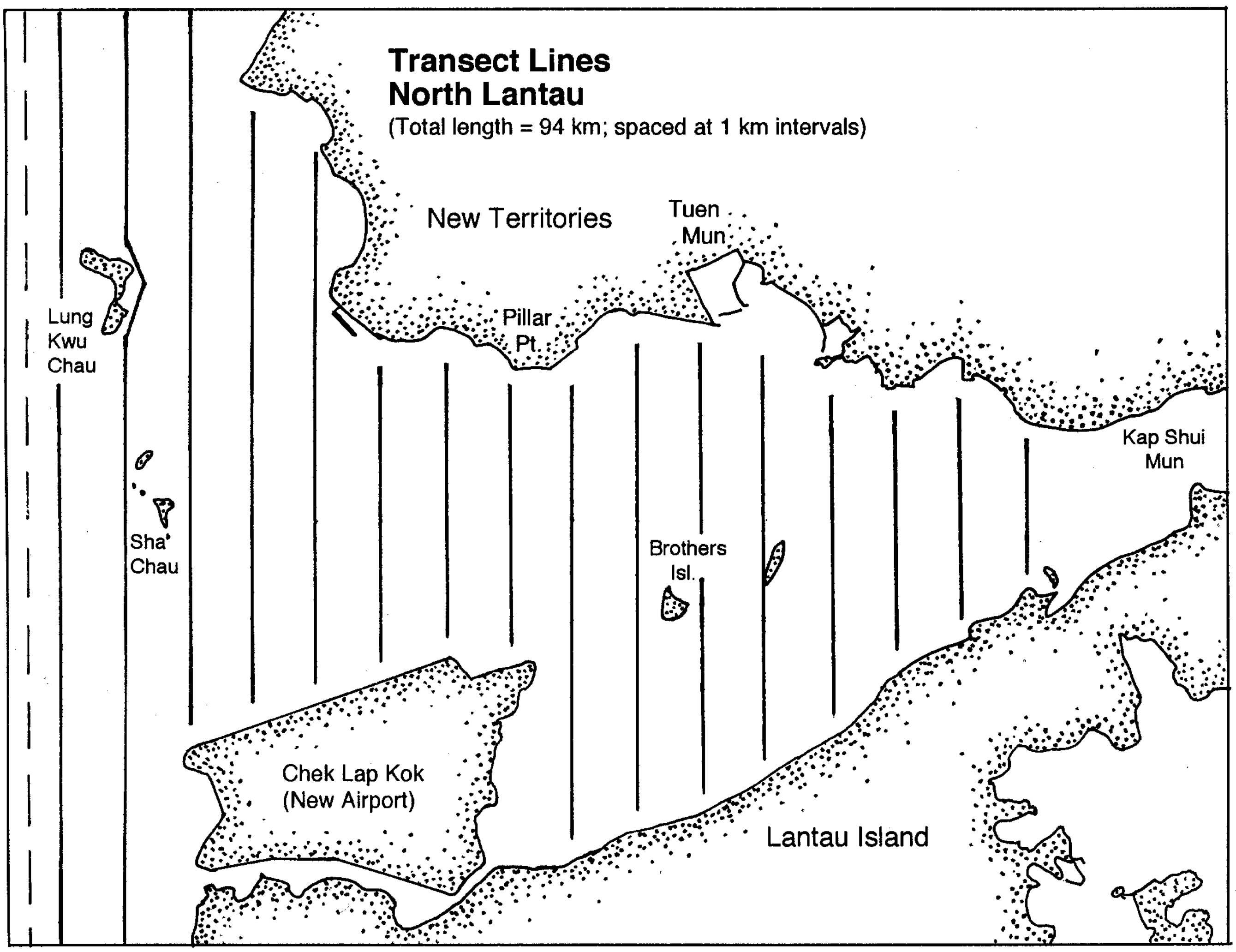

Fig. 2. Map of the primary survey area, North Lantau, showing the transect lines. The transect lines were systematically designed to adequately sample the entire survey area, and were drawn with no reference to dolphin distribution patterns.

laser rangefinder. The laser has a useable range of 25–1,000 m and a reported accuracy of ± 1m. The laser requires a target somewhat perpendicular to the beam path, which acts as a reflecting surface. Thus, it can not be used to obtain a reading off the water's surface, and taking a reading off a distant dolphin's back or dorsal fin was difficult. Nevertheless, the laser binoculars have been used extensively to enhance the ability of the observers to estimate distance. Also, they can be used to take readings off ships, rocks, buoys, and other floating objects near dolphin groups, to be compared with subjective estimates, thereby increasing the accuracy of distance estimates to the dolphins. The senior author conducted periodic distance calibration exercises with observers, making use of the laser binoculars to aid in ensuring that observer distance estimation was accurate, and to collect data for distance calibration, if not.

Individual dolphins can be identified, based on markings on their backs and dorsal fins (Plate 1). When a dolphin sighting was made, the observers generally suspended survey effort and diverted the vessel to obtain better group size estimates and photographs for photo-identification (Würsig and Jefferson 1990). Photos were taken using *Canon* and *Nikon* 35-mm autofocus cameras and lenses of 35–350 mm focal lengths. The primary equipment was a *Canon* EOS 5 databack camera, with a *Canon* 300 mm / f 2.8 lens equipped with a 1.4 X teleconverter. This extremely fast lens allowed sharp, fine-grained, photos to be taken with colour slide films of 50–100 ISO, even on overcast days. Most photographs were taken by the senior author, but other photographers were instructed to attempt to photograph all members of the group, regardless of whether or not they appeared distinctive.

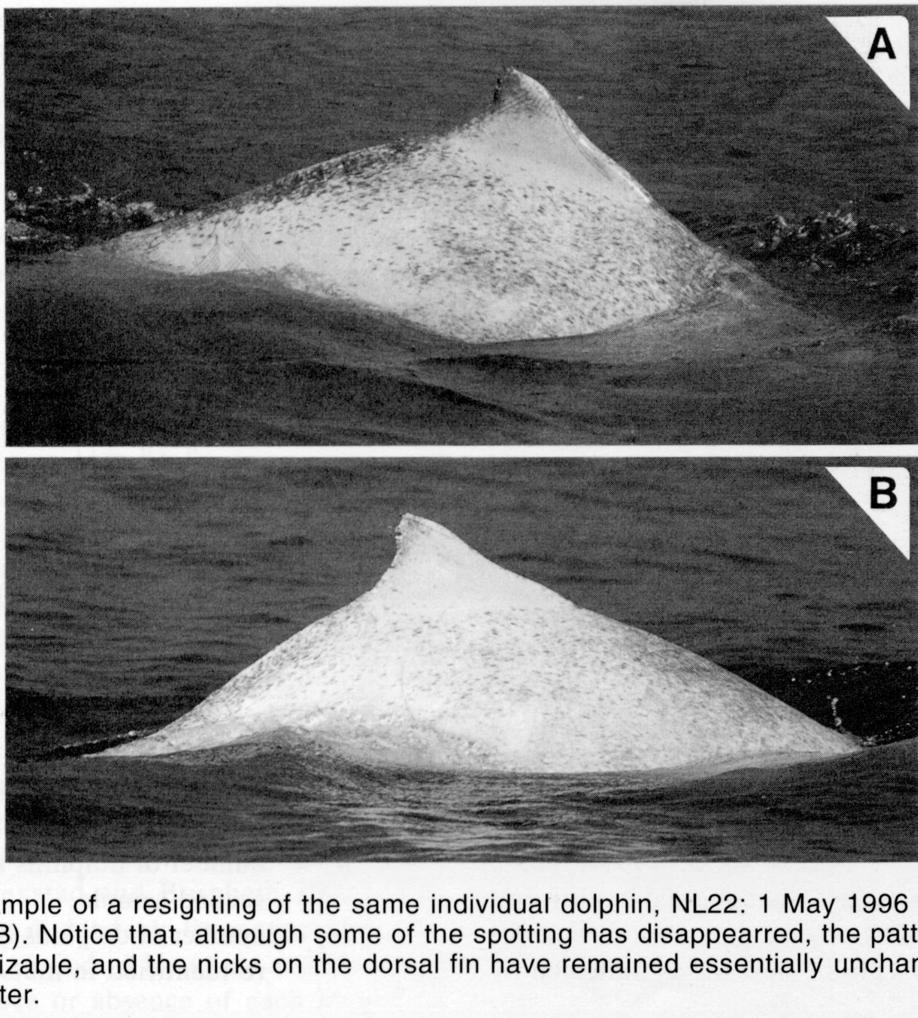

Plate 1. An example of a resighting of the same individual dolphin, NL22: 1 May 1996 (A) and 15 April 1997 (B). Notice that, although some of the spotting has disappearred, the pattern is still easily recognizable, and the nicks on the dorsal fin have remained essentially unchanged almost one year later.

Analysis methods

Estimates of density and abundance were calculated from the the survey data using line transect methods, with the DOS computer program DISTANCE (Laake *et al.* 1994). Estimates of density, abundance, and the associated coefficient of variation were made using the following formulae (Buckland *et al.* 1993):

$$\hat{D} = \frac{n \hat{f}(0)\, \hat{E}(s)}{2L}$$

$$\hat{N} = \frac{n \hat{f}(0)\, \hat{E}(s)\, A}{2L}$$

$$C\hat{V} = \sqrt{\frac{\hat{var}(n)}{n^2} + \frac{\hat{var}[\hat{f}(0)]}{[\hat{f}(0)]^2} + \frac{\hat{var}[\hat{E}(s)]}{[\hat{E}(s)]^2}}$$

where D = density (of individuals),

- N = abundance (of individuals),
- n = number of on-effort sightings,
- $f(0)$ = value of the probability density function at zero perpendicular distance,
- $E(s)$ = unbiased mean group size,
- A = area of region for which abundance is estimated,
- L = length of transect lines surveyed,
- CV = coefficient of variation, and
- var = variance.

Although sightings occurred out to a perpendicular distance of 1,600 m, the vast majority of sightings were within 750 m, and sightings beyond this distance were truncated to remove outliers and to accommodate modelling (Buckland *et al.* 1993). An estimate of group size corrected for size-bias was calculated using linear regression, with $\log_e$ of group size regressed against detection probability; DISTANCE used the corrected estimate if it was significantly different from the average group size (Laake *et al.* 1994). Three models were fit to the distance data (uniform, Hazard Rate, and half-normal) and the model chosen was that with the best fit, as indicated by the lowest value of Akaike's Information Criterion (AIC). Variances were estimated using the defaults in program DISTANCE - empirical for var(n) and theoretical for var[f(0)] (Laake *et al.* 1994).

Photographs taken during transects were sorted, and recognisable individuals were identified and compared with the current photo-identification catalog. In this population of hump-backed dolphins, the color pattern changes dramatically throughout the life of the dolphin, and spot patterns on juveniles and subadults eventually disappear as they become older adults (Plate 1). Each identified individual was placed into one of six age classes, based on body size and color pattern development (Plate 2). Primary features for identification were scars, nicks, injuries, and deformities on the back and dorsal fin; spot patterns were used only in association with other, more permanent, features (Plate 1). A computer database corresponding to the identification catalog was maintained using the program ENDNOTE®. A record of the first sighting and all subsequent resightings was kept in the database, and codes for distinctive features aided in sorting and matching of photographs.

A simple estimate of the total number of individuals that use Hong Kong waters and the associated coefficient of variation were made from the photo-identification data, using Bailey's modification of the Petersen two-sample model, with the following formulae (Seber 1982; Hammond 1986):

$$\hat{N} = \frac{n_1 (n_2 + 1)}{(m_2 + 1)(1 - \hat{p})}$$

$$C\hat{V} = \hat{N}^{-1} \sqrt{\frac{n_1^2 (n_2 + 1)(n_2 - m_2)}{(m_2 + 1)^2 (m_2 + 2)} + \frac{\hat{var}(1 - \hat{p})}{(1 - \hat{p})_2}}$$

where N = abundance,

- n_1 = number of dolphins identified in the first sample,
- n_2 = number of dolphins identified in the second sample,
- m_2 = number of dolphins from first sample re-identified in the second sample,

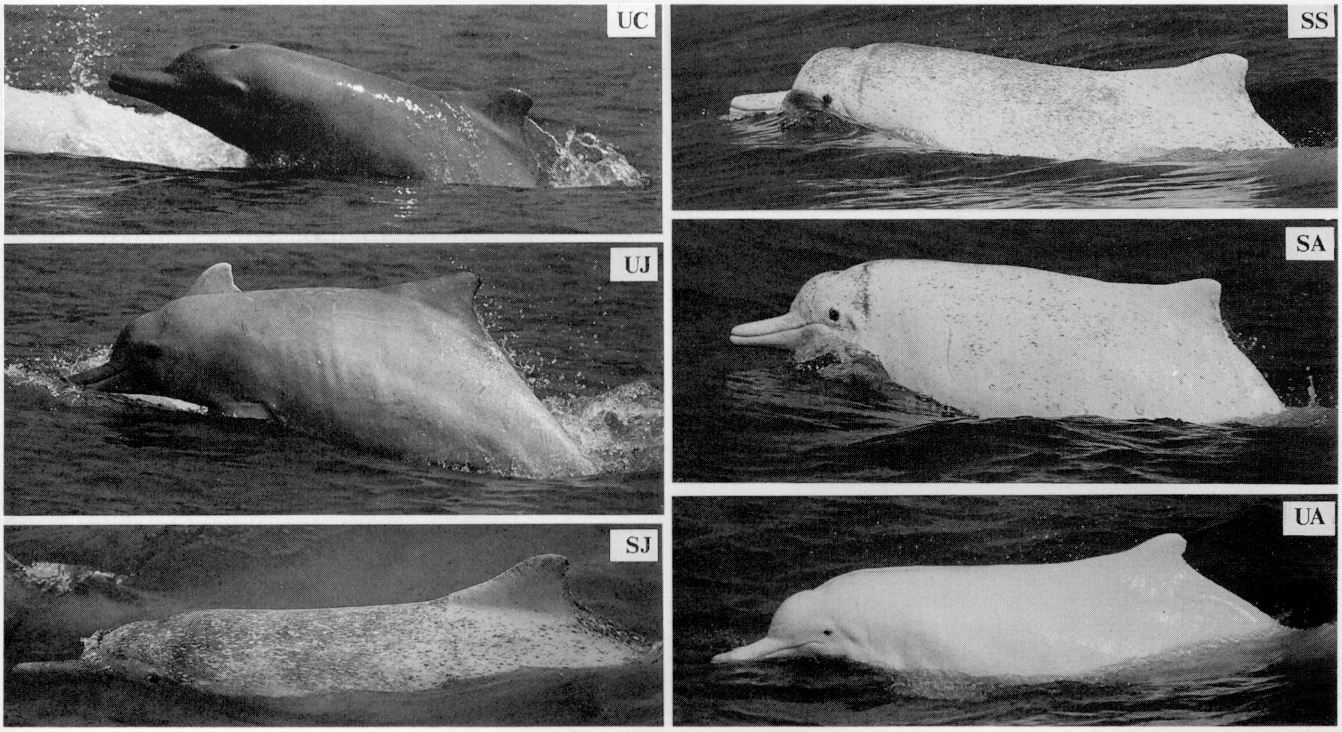

Plate 2. Age classes used in the study of hump-backed dolphins in Hong Kong: unspotted calf (UC), unspotted juvenile (UJ), spotted juvenile (SJ), spotted subadult (SS), spotted adult (SA), and unspotted adult (UA). It should be noted that this progression of color patterns is a 'working hypothesis,' and the exact sequence is not known. For instance, recent evidence suggests that at least some animals may retain dense spotting well into adulthood. It is possible that there is some sexual dimorphism, but this remains to be investigated.

p = proportion of animals that are unidentifiable, and
CV= coefficient of variation.

To approximate what proportion of the dolphins are unidentifiable, we examined photographs with excellent image quality for photo-identification. Only the quality of the image, not the distinctiveness of the dolphins contained, was used in selection of slides. Of 94 photographs in which the dolphin image was in focus and filled at least 15% of the frame, 57 showed an identifiable individual. This suggests that 61% of the dolphins are identifiable and 39% are not identifiable.

In addition, a more sophisticated mark-recapture approach was taken. An estimate of abundance was made using the computer program CAPTURE (Rexstad and Burnham 1991). The study period was divided into three approximately-equal sampling period of about six months each. Data on presence or absence of each identified individual in each period were entered into CAPTURE and the Chao model (M_h) was invoked to estimate abundance. This model allows for capture probabilities to vary by individual animal (Otis *et al.* 1978) and thus may alleviate one of the major biases associated with cetacean abundance estimates calculated from photo-identification data (see discussion below).

Results

Distribution

A total of 16,510 km of trackline were surveyed in Hong Kong and Chinese waters immediately adjacent to Lantau Island. Of this total, 13,078 km occurred in conditions of Beaufort 0–3, and were used in calculation of sighting rates and abundance (see below). The majority of effort (7,655 km, or 58.5%) was focussed on the North Lantau area, where earlier studies had suggested hump-backed dolphins are most common and where Hong Kong's new airport at Chek Lap Kok is being built. The other survey areas were covered as shown in Figure 3. Because of logistical problems, Mirs Bay was not systematically surveyed, but three vessel and eight helicopter trips covered the area, providing opportunities to observe hump-backed dolphins, if they occurred there.

The survey database contained information on sightings of 891 groups of hump-backed dolphins. The vast majority (839 groups, or 94.2%) of these sightings occurred in the area north of Lantau Island, but several sightings were made in the East Lantau, South Lantau, and Deep Bay study areas as well. In addition, sightings were made in Pearl River waters west of Lantau Island during transits through the area, and sighting rates there were high (Fig. 3). There were no sightings of hump-backed dolphins in the eastern areas of Lamma, Po Toi, Sai Kung and Mirs Bay (Figs. 1 and 3).

Hump-backed dolphins occurred throughout the North Lantau study area (Fig. 1). However, they did not appear to be uniformly distributed within these waters. The area between the northern Lantau coastline and the east coast of Chek Lap Kok was notable for the paucity of sightings. Similarly, the New Territories coastline from about Pillar Point east to Kap Shui Mun had very few sightings.

On the other hand, the rectangle bounded by Lung Kwu Chau, Sha Chau, the northeast corner of the airport platform, and Pillar Point appeared to have the highest concentration of dolphins in the area. Dolphins were seen closest to shore along the coast of Lung Kwu Chau, within the boundaries of a newly-established marine protected area, the Sha Chau/Lung Kwu Chau Marine Park (Leatherwood and Jefferson 1997).

Although they were commonly seen in the

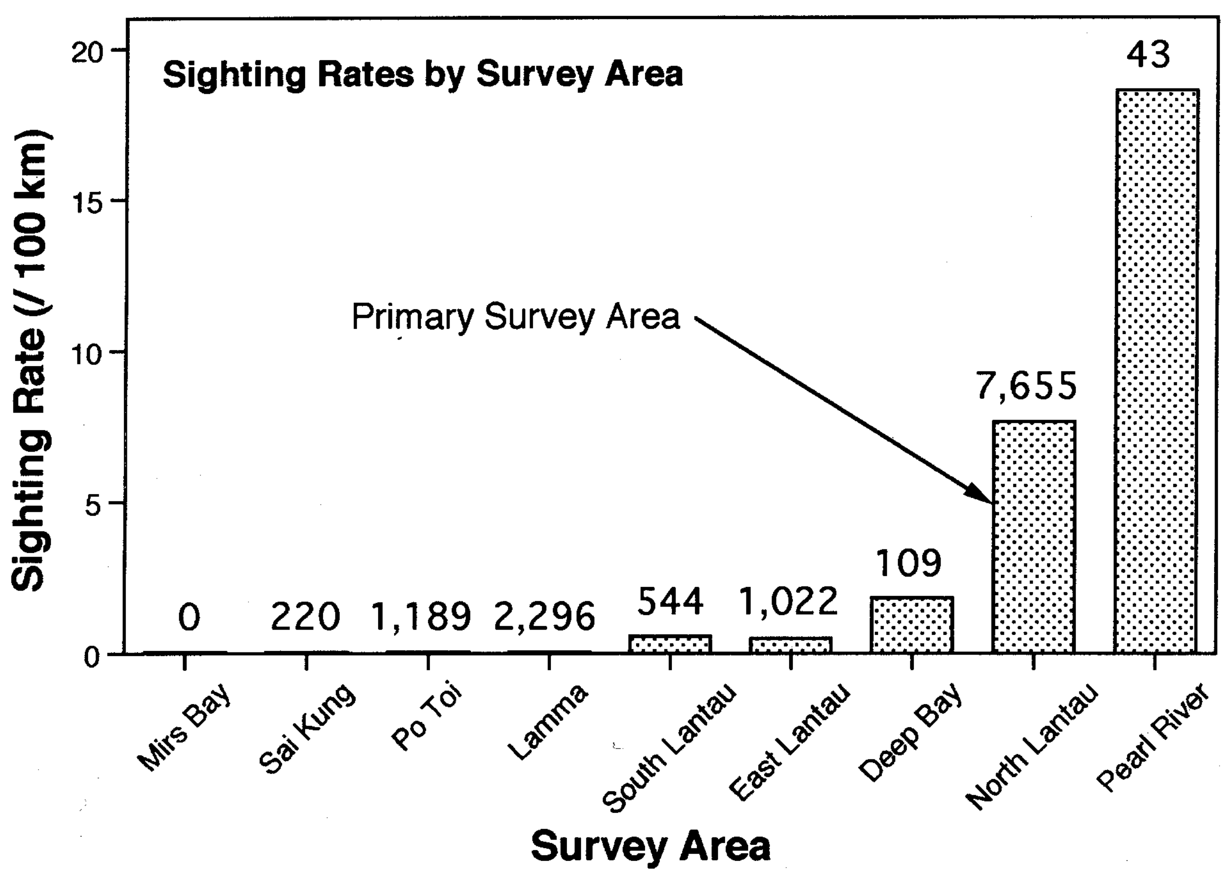

Fig. 3. Sighting rates of hump-backed dolphin groups in the different survey areas. The numbers above the bars represent the number of kilometers of trackline surveyed in that area (calculated from Beaufort 0–3 data only).

western part of the North Lantau study area throughout the year, there did appear to be some seasonal variation in dolphin occurrence in other areas. Sightings in the eastern area of North Lantau, around the Brothers Islands and eastward, tended to occur mostly in the summer and autumn months. Similarly, sightings in the South Lantau area were most common in summer and autumn, and East Lantau sightings occurred primarily in the autumn and early winter months (Fig. 1). A more detailed examination of seasonal distribution patterns will be presented in a future publication.

Estimates of abundance

Groups were considered to be the targets of the surveys. Most hump-backed dolphin groups were small; singles and pairs were most common (Fig. 4). Although group size data are not normally distributed, and thus averages may not represent the best estimates of group size, they were reported here for comparative purposes (Fig. 4). Overall average group size was 3.6 (± s.d. 3.55 animals, n = 850), and groups associated with pair trawlers were significantly larger than other groups (one-way ANOVA, F = 166.96, df = 848, $p < 0.001$). Groups of greater than 10 were relatively rare, and were usually opportunistic aggregations of animals feeding behind pair trawlers. Pair trawlers appeared to be very important as aggregating points for the animals, as well as representing important sources of food.

Several studies have recently shown that Beaufort sea state can have an important effect on line transect estimates for harbour porpoises. These studies showed that using data from higher sea states will cause underestimation of abundance (Teilmann 1995; Palka 1996). In order to avoid this problem, we first calculated abundance estimates stratified by Beaufort sea state (Fig. 5). This exercise showed that, although sighting rates dropped off almost linearly as Beaufort increased, abundance estimates were relatively stable through Beaufort 3. Only the estimate for Beaufort 4/5 showed a significant decrease (Fig. 5). Thus, sighting and effort data collected during conditions

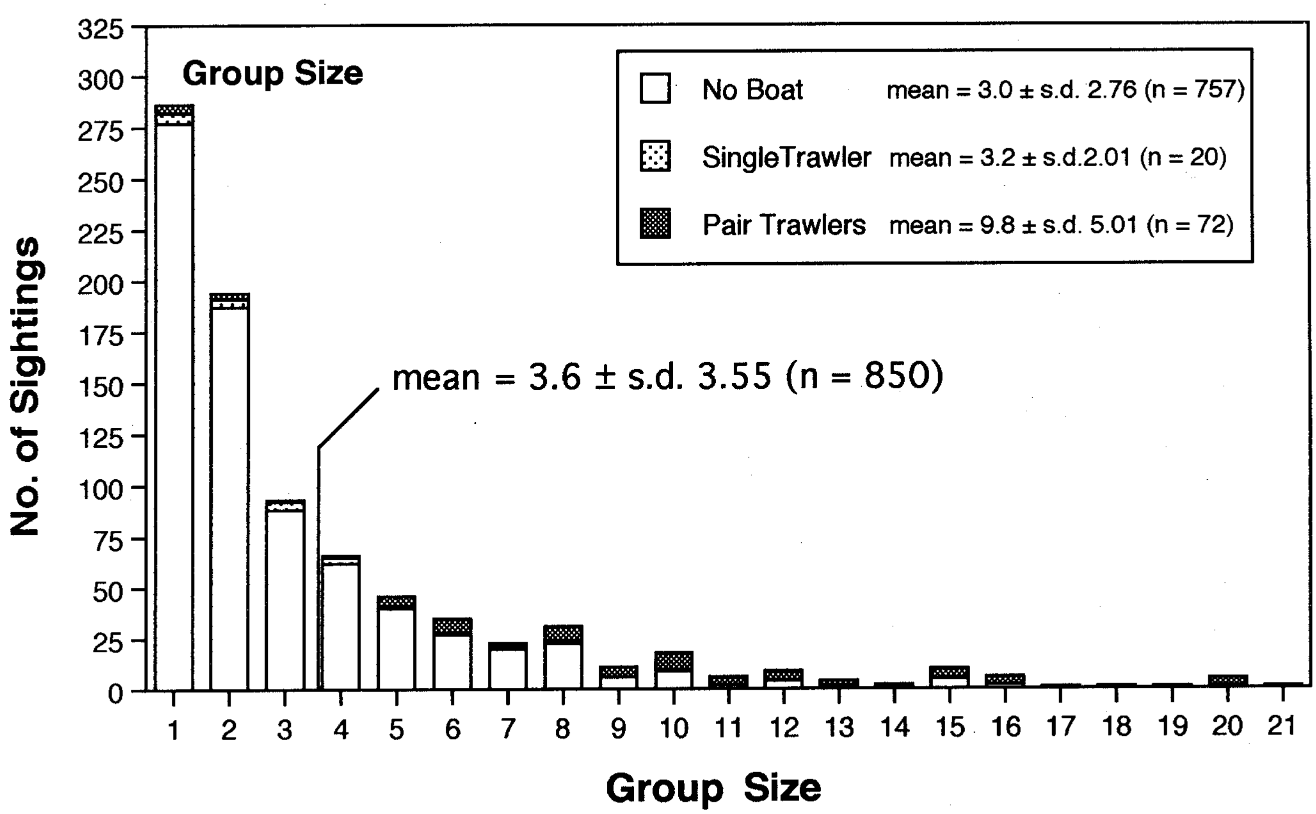

Fig. 4. Distribution of group sizes of dolphins in Hong Kong by association with different types of fishing vessels.

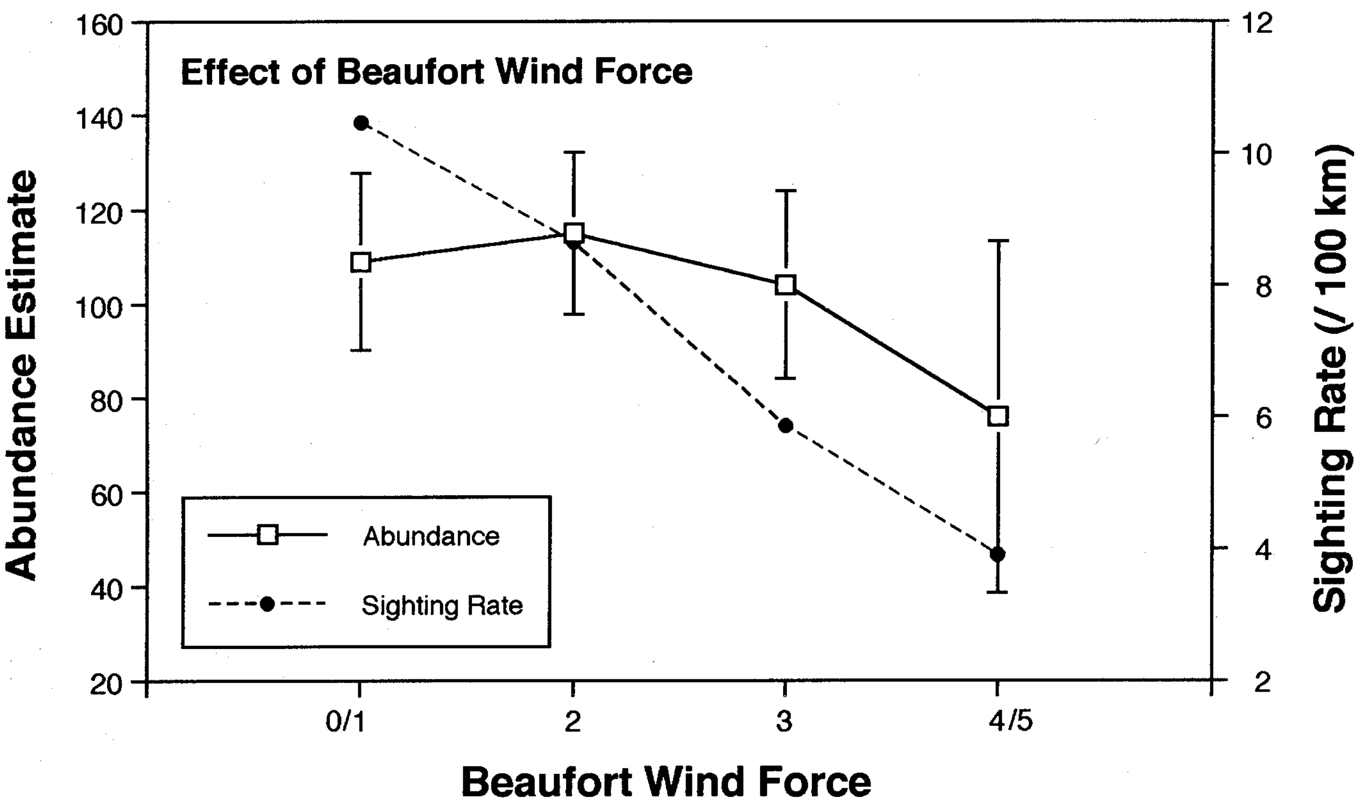

Fig. 5. Effect of Beaufort wind force on dolphin sighting rates and estimates of abundance. Vertical bars represent the 95% confidence limits of the estimates. Differences between Beaufort states were statistically significant (Chi-square = 8.85, df = 3, $p < 0.05$). However, after deletion of Beaufort 4/5 data, there was no significant difference (Chi-square = 0.56, df = 2, $p > 0.05$).

of Beaufort 4/5 were discarded before calculating further estimates of abundance.

Preliminary estimates of density and abundance for the North Lantau study area, based on line transect analysis of data collected in conditions of Beaufort 0–3, through May 1997, are shown in Table 1. The Hazard Rate model with Cosine Adjustment was chosen, using AIC, for calculation of all estimates. The AIC values for the selected models ranged from 321 to 926. The estimate of average seasonal abundance was 109 dolphins (95% confidence interval = 87 – 137). Separate seasonal estimates ranged from 88 (spring) to 155 (autumn) (Table 1; Fig. 6). Although estimates for winter through summer were very similar, there appears to have been a significant increase in dolphin numbers north of Lantau in the autumn (Table 1; Fig. 6).

So far in this study, 101 individual hump-backed dolphins have been identified in Hong Kong and adjacent Chinese waters (two of these were identified from photographs taken before the study started) from markings on the back and dorsal fin. The total size of the photo-identification catalog is currently 100 individuals, however, as one known individual was recently found dead. Many individuals (45%) have not been resighted, but others have been seen up to 20 times.

New individuals are still being added to the catalog. To determine whether we were approaching a plateau in the number of new identifications, the cumulative number of new individuals identified per month was plotted (Fig. 7). The number of rolls of film taken per month was used as an index of photographic sampling effort. The leveling-off of the discovery curve, which was apparent in several places, was largely

Table 1. Summary of line transect parameters and seasonal estimates of density (D) and abundance (N) of hump-backed dolphins in the North Lantau area

Season	n*	$\hat{E}(s)$	L (km)	$\hat{ESW}$ (m)#	$\hat{D}$ (km^{-2})	$\hat{N}$	95% CI	$\hat{CV}$ (%)
Winter	208	2.92	2621.9	189	0.61	90	65–124	16.82
Spring	114	2.92	1826.2	150	0.61	88	61–128	18.98
Summer	72	2.10	1023.4	116	0.64	93	55–158	27.12
Autumn	147	3.37	1463.7	159	1.07	155	97–249	24.40
Overall	541	2.78	6935.2	145	0.75	109	87–137	11.60

* Represents the number of sightings used in the analysis, after truncation.

\# SW is the effective strip width, which is used as a measure of sightability. It is estimated as the inverse of f(o).

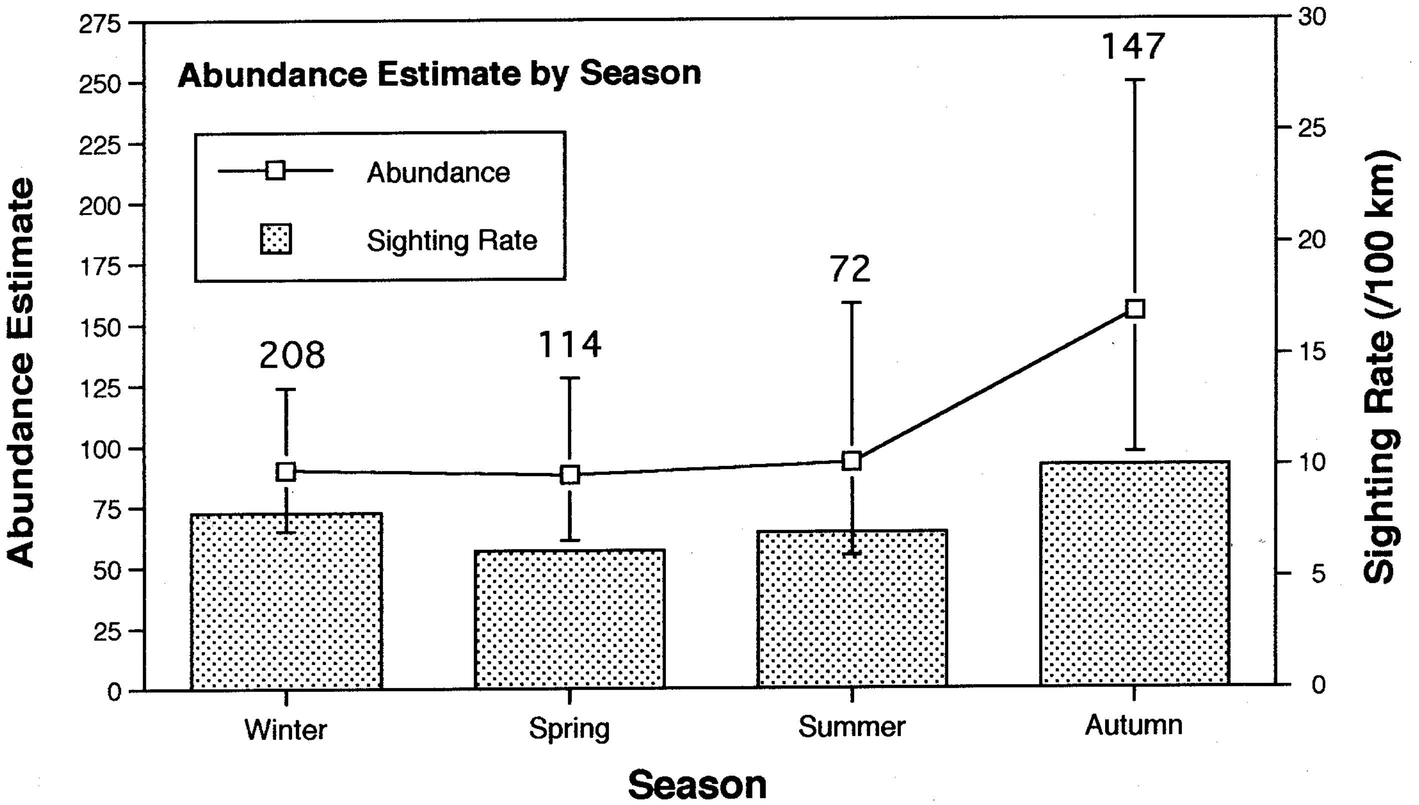

Fig. 6. Seasonal estimates of abundance of dolphins in the North Lantau area. Vertical bars are the 95% confidence limits of the estimates and the numbers above are the numbers of on-effort sightings (after truncation) used in calculation of the estimates. Differences by season were highly statistically significant (Chi-square = 29.57, df = 3, $p < 0.001$).

a result of low photographic sampling effort. January 1996 had the greatest number of new identifications (29), but also the greatest photographic sampling effort (58 rolls taken).

Two mark-recapture estimates of abundance were calculated from photo-identification data. The preliminary Petersen estimate for the number of dolphins that use Hong Kong waters was calculated to be 208 individuals (CV = 17.26%). The Chao estimate, calculated using program CAPTURE, was 246 individuals (CV = 17.27%).

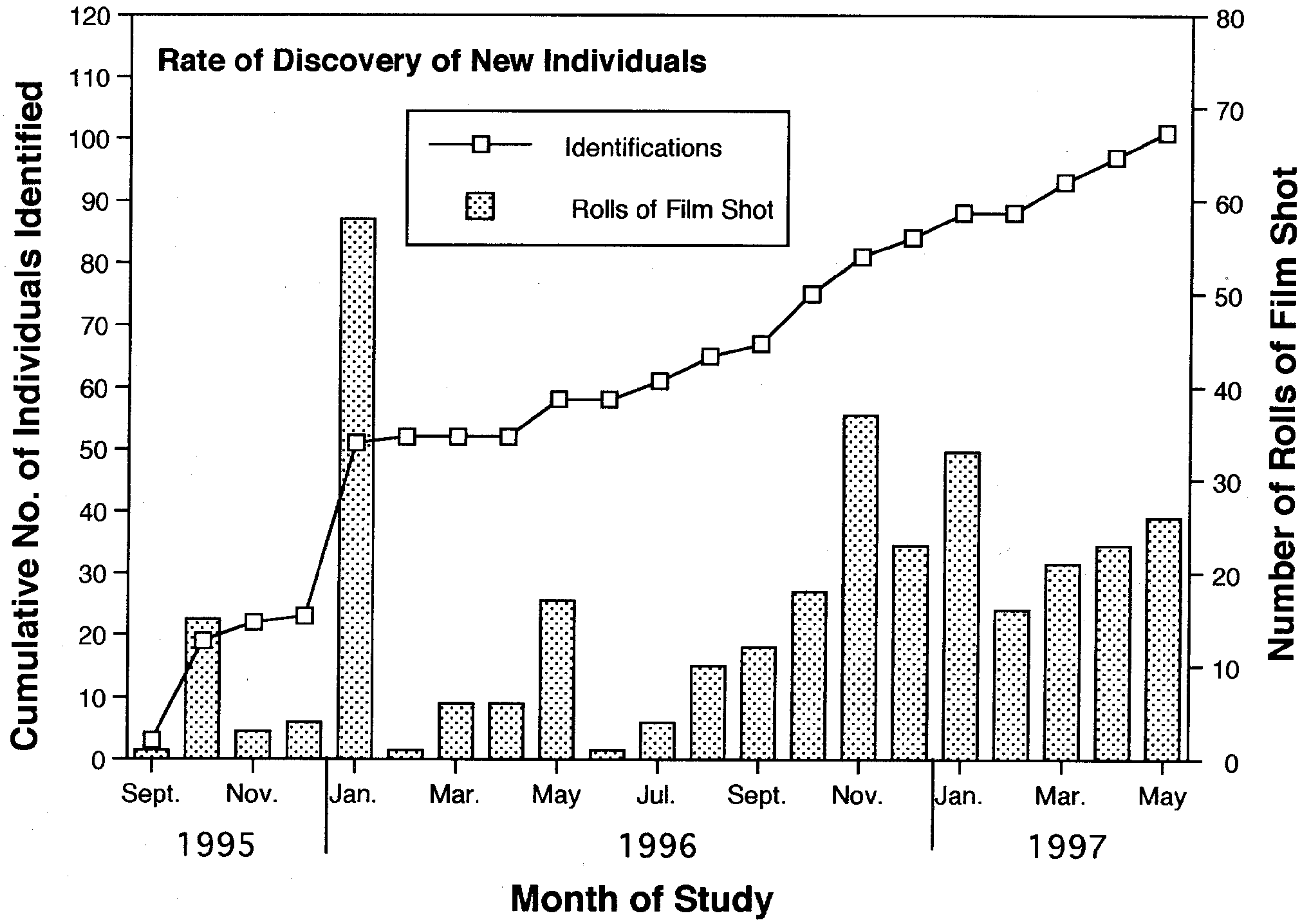

Fig. 7. Discovery curve of the cumulative number of individual dolphins identified to date (31 May 1997) in the study. The bars represent the number of rolls of 36-exposure film taken in that month - a measure of photographic sampling effort.

Discussion

Distribution

Dolphins occur in the North Lantau area in significant numbers throughout the year, but there is some evidence that certain subareas are used primarily in particular seasons. For example, dolphins were commonly seen in late summer and autumn in the area around the Brothers Islands, east of the new airport. However, dolphins were rarely seen in this area in the winter and spring. Similarly, the area south of Lantau Island appears to be used primarily in the summer and autumn (Parsons 1997).

Unfortunately, so far it has only been possible to survey a small proportion of the probable range of the population. From recent data collected to the west of Hong Kong waters, it appears that the population inhabits a large area and is centered around the mouth of the Pearl River (Yang and Chen 1996; Wu and Chen 1996), most of which occurs in waters of the PRC. Because of logistical and political constraints, we have not been able to survey most of the Chinese waters of the Pearl River delta (although surveys are scheduled to begin there in mid to late 1997). We have, however, obtained some information about dolphins in this area. We have received second-hand reports of sightings of dolphins from at least as far as Macau, on the western side of the Pearl River delta. It appears that the region around Neilingding Island (just west of Lung Kwu Chau), for instance, is heavily used by dolphins (Yang and Chen 1996). From the small amount of survey effort collected so far in Chinese waters west of

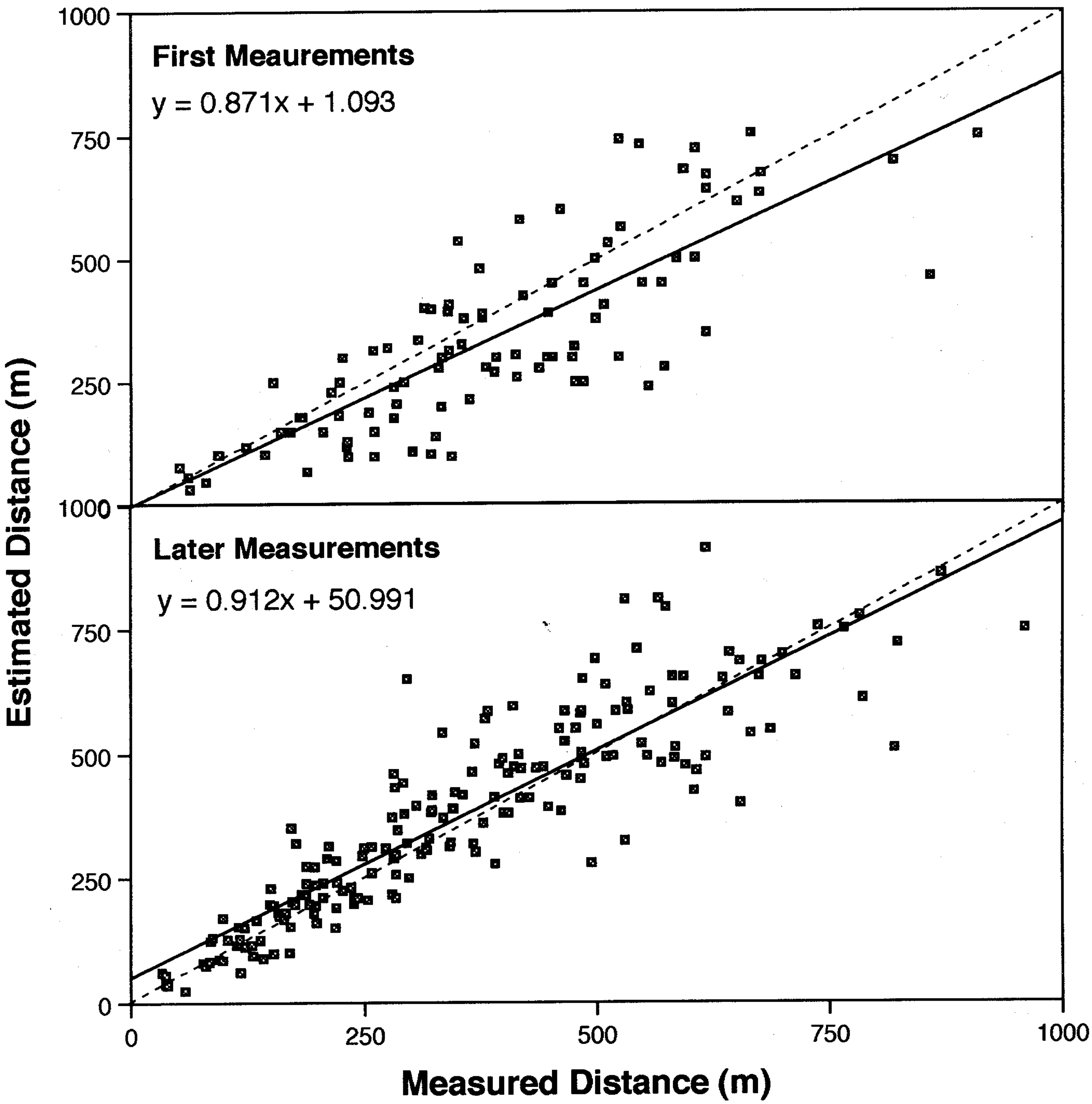

Fig. 8. Results of distance calibration exercises, showing radial sighting distances for early measurements and later measurements (after observers began using laser rangefinder binoculars). The solid lines are the regression lines fitted to the empirical data, and the dashed lines are the theoretical lines representing no bias.

Lantau Island, it appears that dolphin density there is very high (Fig. 3). The western limits of the population have not been clearly defined. To the east, it is apparent from our surveys and from stranding data (Parsons 1997), that hump-backed dolphins occur only rarely, if at all, in waters east of Lamma and Hong Kong islands.

Dolphins are often seen feeding near active fishing vessels in Hong Kong. Pair trawling is one specific type of fishing operation that is very important in influencing the distribution, movements, and group structure of the dolphins.

Of Hong Kong's 2,232 fishing vessels, over 10 m in length, pair trawlers are the most common type, comprising 26% of the fleet (Wilson and Wong 1996). During the autumn, winter, and spring seasons, hump-backed dolphins are often seen feeding behind these vessels in North Lantau waters, frequently in large groups of up to 21 animals (Fig. 4). In fact, 23 of 24 (96%) pair trawlers observed fishing in the North Lantau area have had dolphins behind them. Pair trawlers tend to act as 'magnets,' collecting dolphins as they move through an area. We have observed dolphins staying with these vessels for several hours, and some individual dolphins appear to use pair trawlers quite heavily. A wide variety of cetacean species have been found to feed in association with trawling operations (Fertl and Leatherwood in press).

Estimates of abundance

The line transect estimates of abundance presented above are not population estimates in the strict sense. Because the survey data have been collected in a very limited portion of the population's apparent range, the densities obtained have not been extrapolated to a larger area to estimate total population size. If densities in waters of the Pearl River outside of Hong Kong are significantly higher or lower than those in North Lantau, such extrapolation could give a very misleading overall estimate of population size. We feel that this should not be attempted until there are representative data from throughout the Pearl River delta. Similarly, although we have seen dolphins in other survey sub-areas around Lantau Island (Fig. 1), because of small sample sizes we have not made any attempt to estimate abundance in regions outside of North Lantau. This will be done when larger sample sizes are obtained.

There appear to be moderate seasonal changes in dolphin distribution and abundance in Hong Kong, with the highest numbers of dolphins using the North Lantau area in the autumn, and seasonal movements into some of the more southern and eastern waters around Lantau in summer and autumn (Fig. 6). In southern China, winter is the dry season with the lowest discharges from the Pearl River; summer is the wet season with the highest fresh water input to Hong Kong waters (Broom and Ng 1996). The early autumn months of September and October still have high levels of freshwater input from the Pearl River, and this is also when pair trawlers begin to fish more heavily in Hong Kong's western waters. Thus, it appears that dolphins may follow the widening influence of the Pearl River in summer, and their distribution may adjust accordingly. This hypothesis is supported by the observation that the area south of Lantau Island appears to be used primarily in summer and autumn (Parsons 1997). It is also possible that the observed changes in dolphin abundance north of Lantau can be explained, at least partially, by the shift in pair trawler distribution. We plan to examine these hypotheses further with additional work in and around the Pearl River estuary.

There are several assumptions inherent in line transect analysis, and this technique can give accurate estimates only as long as these assumptions are met, or alternatively, if corrections are made to compensate for any violations. Buckland *et al.* (1993) outlined three primary assumptions, and the validity of these assumptions to the present study is discussed below.

The central assumption of line transect analysis is that all animals on the trackline at the time of passage of the survey platform are detected. This assumption can be seriously violated by long-diving cetaceans, such as sperm whales (*Physeter macrocephalus* Linnaeus, 1758) and beaked whales (Ziphiidae), and generally this is dealt with by incorporating the detection function [g(0)] into the line transect equation, and then using empirical data to estimate its value [thus g(0) becomes a correction factor]. For most dolphins, which have shorter dive times, there is generally not so much of a problem with violation of this assumption. A violation would only lead to underestimation of abundance, not an overestimate.

The second assumption is that animals do not make responsive movements prior to detection by observers, and that no animals are counted twice in the same sample. Violation can result in either overestimation or underestimation of abundance. Hump-backed dolphins are much better survey targets than many other small cetaceans, because they do not ride bow waves (and thus usually do not appear to be attracted to the survey vessel) and do not actively avoid vessels, like some porpoises and a few species of dolphins routinely do.

Analysis of photo-identification data reveals that some individuals are occasionally resighted on the same day; however, none have been resighted on the same transect line. Resightings on the same day are relatively rare, and when they happen, it is generally a single individual that is resighted later with a different group of associates (preliminary analysis indicates that there appears to be a great deal of fluidity in social associations of Hong Kong hump-backed dolphins). For these reasons, there should be no problem in the present study with violation of this assumption (S. T. Buckland pers. comm.).

The third primary assumption is that measurements of angle, distance, and group size are made without error. Really, accurate measurement is an assumption in any scientific study, but as in any other case, the problems caused by violations of this assumption will vary, depending on the severity and consistency of the bias. In practice, even moderately large errors can be tolerated, as long as they are random (thus, the average of a large sample of measurements would be close to the true average). Most troublesome are systematic biases in data collection, such as consistent overestimates of group size or underestimates of distance.

Group sizes in this study were estimated in the field and are thus subject to error (primarily overestimation of average group size, resulting from the lower probability of detecting small groups at great distances). However, the size-bias correction feature of program DISTANCE corrects for this bias. Angles are generally computed directly from successive compass bearings (taken on the dolphin group and the heading of the vessel). These compass bearings are read to the nearest degree from a compass built into the binoculars. Thus, the probability of systematic bias in angle estimation is quite small.

Problematic errors in data collection most likely occur in estimation of sighting distances, which are estimated by eye by shipboard observers. The reticles that are built into the *Fujinon* and *Nikon* binoculars are often used to calculate distance in other cetacean surveys in offshore areas (Barlow and Lee 1994) but will not work for inshore waters of Hong Kong, where we can only rarely see the horizon. We experimented with the use of a clinometer to calculate sighting distance from the declination angle to a sighting, but we found that it was impractical to use on the relatively small survey vessels used in Hong Kong, where eye height is so close to the water.

When we obtained the *Leica Geovid* laser rangefinder binoculars in July 1996, we quickly realized that we had a significant problem with underestimation of sighting distances (generally by at least 15%). Estimates made without correcting for this bias would likely overestimate density and abundance. However, distance calibration exercises have allowed us to calculate a correction factor, which was used to correct all the pre-July distance estimates. Also, since feedback has been given to the observers on the results of the calibration exercises (and observers have had the opportunity to practice with the laser binoculars), we have noticed an increase in the average sighting distance, and these more recent data do not appear to suffer from the underestimation problems experienced earlier (Fig. 8). Also, in the more recently collected data, there is less scatter about the regression line, especially in the distance range that would have the greatest effect on abundance estimates (< 500 m). Thus, the estimates presented in this paper do not appear to suffer from significant problems associated with errors in distance estimation.

The estimates of abundance from photo-identification data are higher than the corresponding estimates from line transect analysis. However, it should be noted that estimates produced by the two techniques are not directly comparable. The line transect estimate provides information on the number of dolphins in the area at the time of the surveys, regardless of whether they are the same individuals staying in the area, or new ones moving through. The photo-identification technique estimates the number of different individuals that use the area. The latter may be thought of as the size of the 'pool' of individuals that occur there at some time during the study. These two estimates will not be directly comparable until we have data from throughout more of the range of the population (in which case, the above distinction will not apply).

It should also be noted that the Petersen mark-recapture model has several assumptions, which are listed in Hammond (1986) as follows:

1. The (sampled) population is closed,
2. All animals have the same probability of being identified,
3. Marking (photographing) does not affect catchability of an animal,
4. The second sample is a simple random sample,
5. Animals do not lose their marks, and
6. All marks are reported upon discovery.

Of these, only the first two are likely to be problematic. The first assumption is definitely violated in this study, as indicated by the fact that new individuals are still being identified (Fig. 7). In addition, so far sampling has only occurred in a small portion of the range of the population in the Pearl River estuary. These points indicate that the mark-recapture estimate does not represent a complete estimate of total population size, unless all dolphins use the Lantau area as an important part of their home range (from data collected so far, this seems unlikely).

The second assumption is also likely violated in this study, judging from preliminary impressions on the behavior of the animals and the fact that it is a widespread problem in cetacean photo-identification studies (often referred to as 'heterogeneity,' Hammond 1990). Correcting for this bias may well be the most difficult problem in obtaining accurate estimates of abundance for these dolphins from photo-identification data. However, a distinct advantage of the Chao mark-recapture model is that it allows for some heterogeneity (essentially dropping assumption # 2 above), and thus lessens the impact that this factor will have on the resulting abundance estimates. Thus the Chao estimate of 246 animals is the closest approximation that we have to a population estimate for the Pearl River delta breeding population, or stock, but its true size is probably larger than any of the estimates calculated so far.

Conclusions

The results of the present study indicate that both techniques used in this study, line transect analysis of vessel survey data and photo-identification of individuals, are well suited to Indo-Pacific hump-backed dolphins in Hong Kong waters. The calm protected waters, and the morphology and behavior of the animals make such studies much easier than for many other species of small cetaceans, and the use of laser rangefinder binoculars to calibrate sighting distance estimates has greatly improved the quality of the line transect data.

Both techniques can tell us something about the abundance of the dolphins, and preliminary indications are that they agree that over 150 dolphins use Hong Kong waters. Although neither technique can give us a reliable estimate of total population size at this point, they both suggest that the total number of animals in the Pearl River area is probably at least several hundred animals.

The research summarized in this paper is ongoing. Surveys in North Lantau will continue at a frequency of at least five days each month, and in the future there will be increased emphasis on surveys in the East and South Lantau areas, Deep Bay, and in the southern waters of Hong Kong, some of which are known to be used by hump-backed dolphins, at least seasonally.

In the future, we hope to obtain survey data from a much larger survey area in PRC waters to the west of Hong Kong, as well as to continue to survey all of Hong Kong's waters more extensively. From future line transect and mark-recapture analyses of these data, we hope to be able to estimate total hump-backed dolphin population size and to statistically examine series of estimates for evidence of trends in abundance. This information will play an integral role in the future management and conservation of these little-known dolphins.

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